

# Different PDF approximations useful for LO Monte Carlo generators

A. Sherstnev<sup>1</sup> and R.S. Thorne<sup>2</sup>

1 - Cavendish Laboratory, University of Cambridge,  
JJ Thomson Avenue, Cambridge, CB3 0HE, UK  
and Moscow State University, Moscow, Russia (on leave)

2 - Department of Physics and Astronomy,  
University College London, WC1E 6BT, UK

The goal of this study is to find a prescription for defining parton distributions (PDFs) which are most appropriate for use in those codes where only LO matrix elements (MEs) are used, as in many Monte Carlo generators. We describe a modification of LO PDFs, based on using  $\alpha_S$  at NLO, a specific prescription of the coupling in the QCD evolution, and violation of the momentum sum rule. We compare results with *the truth* – the prediction using NLO for both MEs and PDFs, and the standard LO prediction, finding that the modified PDFs generally produce the best results.

## 1 Introduction

The talk [1] considers the use of PDFs in LO Monte Carlo generators. It is well known that PDFs extracted at different orders of perturbative QCD have large differences in certain regions of  $x$ . This is because missing higher order corrections, both in the parton evolution and in the MEs, play an important role in the extraction of the PDFs by comparison to experimental data. Traditionally, LO PDFs are supposed to be the best choice for use with LO MEs as implemented in most Monte Carlo programs. However, another viewpoint has recently been put forward, namely it has been suggested that NLO PDFs may be more appropriate even for MEs at LO [2]. The main justification for this idea is the claim that NLO corrections to MEs are small, and the total cross-section changes due to the differences in PDFs.

In this contribution we propose another approach, which combines the advantages of both the LO and NLO PDFs. We call the result the LO\* PDFs. Here we present only two examples of comparisons using all three approaches, but many more examples are available in our previous article [3]. However, in this article we additionally introduce another improvement to the modified LO PDFs, namely a change in the scale for the coupling used in the evolution of the partons. This makes the PDFs more consistent with the showering in Monte Carlo codes and has been inspired by feedback concerning the original LO\* PDF approximation [4].

## 2 Parton Distributions at Different Orders

Let us briefly elucidate why the differences between the PDFs at different perturbative orders appear. The difference in the gluon PDF is mainly a consequence of quark evolution, rather than gluon evolution. The small- $x$  gluon is determined by  $dF_2/d\ln Q^2$ , which is related to the  $Q^2$  evolution of the quark distributions. The quark-gluon splitting function

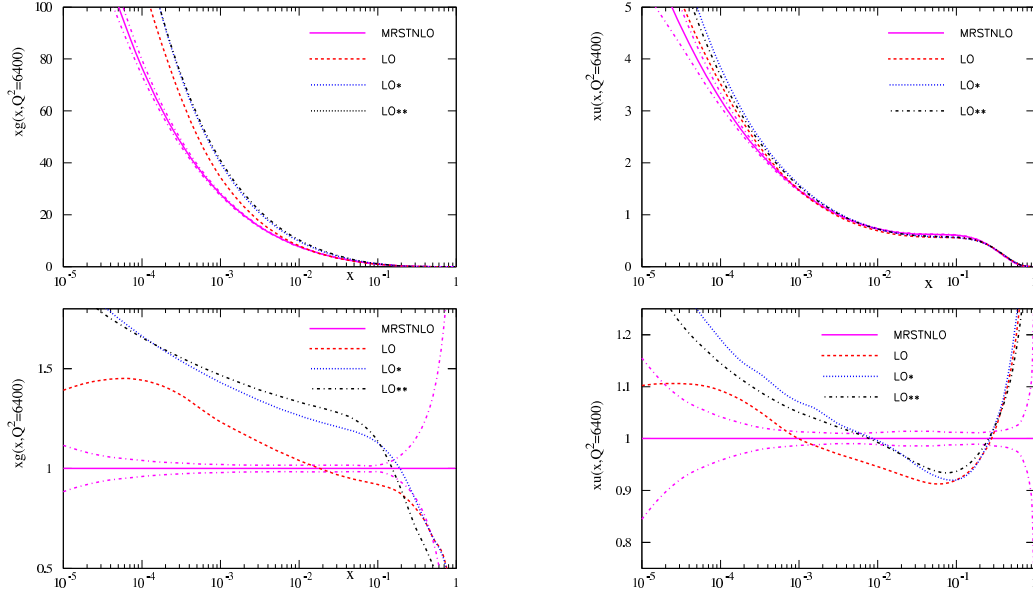


Figure 1: Parton distribution functions for u-quarks and gluons – absolute values (top) and ratio to NLO (bottom) where the uncertainty band for the NLO PDFs is shown.

$P_{qg}$  is finite at small  $x$  at LO, but has a small- $x$  divergence at NLO (and further  $\ln(1/x)$  enhancements at higher orders), so the small  $x$  gluon needs to be much bigger at LO in order to fit data. Differences of the same nature appear in quark distributions at LO and NLO. Most particularly the quark coefficient functions for structure functions in  $\overline{\text{MS}}$  scheme have  $\ln(1-x)$  enhancements at higher orders, and the high- $x$  quarks are smaller as the order increases. Due to the momentum sum rules this is accompanied by a depletion of the quark distribution for  $x \sim 0.01$ . This depletion leads to a bad global fit at LO, particularly for HERA structure function data, which are very sensitive to quark distributions at moderate  $x$ . In practice the lack of partons at LO is partially compensated by a LO extraction of much larger (than at NLO)  $\alpha_S(M_Z^2) \sim 0.130$ . So, the first obvious modification is to use  $\alpha_S$  at NLO in a LO fit to parton distributions. The problems caused due to the depletion of partons have led to a suggestion [5] that relaxing the momentum sum rule could make LO partons rather more like NLO partons where they are normally too small, while allowing the resulting partons still to be bigger than NLO where necessary, i.e for the small- $x$  gluon and high- $x$  quarks. We call the modification the LO\* PDFs. The approach does improve the quality of the LO global fit. The  $\chi^2 = 3066/2235$  for the standard LO fit, and becomes  $\chi^2 = 2691/2235$  for the modified fit with the same data set as in [6] and using  $\alpha_S(M_Z^2) = 0.120$  at NLO. The momentum carried by input partons goes up to 113%. We analysed the consequences of these distributions by comparing to cross-sections using LO and NLO PDFs in LO Monte Carlo generators and to full NLO results – presenting many examples [3].

Here we introduce an additional modification to the LO\* PDFs. We replace the standard QCD scale  $Q^2$  by  $\tilde{Q}^2 = z(1-z)Q^2$  in  $\alpha_S$  dependence on the QCD scale in the splitting function  $P_{qq}$  (freezing  $\alpha_S(\tilde{Q}^2)$  at 0.5 as  $z \rightarrow 1$ ). This automatically takes into account logarithmically enhanced terms [7]. The partons obtained using this further modification are called the LO\*\* PDFs. As for the LO\* PDFs, the output is based on the MRST LO

PDFs [8]. This improves the quality of the global fit slightly further, i.e.  $\chi^2 = 2640/2235$ , and the resulting value of  $\alpha_S(M_Z^2) = 0.115$ , smaller than for the LO\* PDFs. In fig. 1 we illustrate all four PDF prescriptions: NLO, LO, LO\*, and LO\*\*. LO\* and LO\*\* gives more quarks and especially gluons for  $x < 0.1$  than LO. They provide fewer large- $x$  gluons than NLO, but more quarks at large  $x$  (as for LO) and more quarks and gluons than NLO for very small  $x$ . In general, the LO\*\* modification brings little change compared to LO\*, mainly a small increase in gluons for  $x \sim 0.01$ , but in many cross-sections this is countered by the smaller value of the coupling.

prescription	$\sigma_W(\text{nb})$	$\sigma_H(\text{pb})$
$\sigma(\text{ME}_{\text{NLO}} \otimes \text{PDF}_{\text{NLO}})$	21.1	38.0
$\sigma(\text{ME}_{\text{LO}} \otimes \text{PDF}_{\text{LO}})$	17.5	22.4
$\sigma(\text{ME}_{\text{LO}} \otimes \text{PDF}_{\text{NLO}})$	18.6	20.3
$\sigma(\text{ME}_{\text{LO}} \otimes \text{PDF}_{\text{LO}^*})$	20.7	32.4
$\sigma(\text{ME}_{\text{LO}} \otimes \text{PDF}_{\text{LO}^{**}})$	20.2	35.2

Table 1: Comparison of cross-sections using different prescriptions

total cross-sections for the two examples are shown in table 1. For  $W$  production both LO\* and LO\*\* are closer to *the truth* than NLO or LO, which is worst, but LO\*\* gives a slightly worse answer than LO\*. For Higgs production LO\*\* gives the closest number to *the truth* and NLO is worst. The left of Fig. 2 shows two physically important distributions for the first example. The LO PDFs show the worst behaviour in the  $W$ -boson pseudo-rapidity, reflecting the PDF depletion for moderate  $x$ . Our LO\*/LO\*\* modifications do not have this drawback and imitate *the truth* much more accurately. The  $P_T$  distribution shows that we cannot completely simulate the full NLO result with any set of PDFs, though LO\* and LO\*\* give the closest normalizations. The right of Fig. 2 displays the same distributions for our second example. We see that the shapes of all LO approximations are fine, but LO\*\* gives a much better normalization.

As an example of the application of the LO\*\* PDFs we consider the  $W$ -boson production and the Higgs boson production, both at the LHC. For the simulations we used MC@NLO [9], CompHEP [10] and FORTRAN HERWIG [11]. We compare the use of MEs at LO and the PDFs at LO/NLO/LO\*/LO\*\* to a combination of PDFs and MEs at NLO (which we call *the truth*). The

### 3 Conclusions

We have suggested an optimal set of partons for Monte Carlo codes, which is essentially LO but with modifications to make results more NLO-compatible. We call the modification LO\* and LO\*\* PDFs. They are based on three effects: the use of the NLO QCD coupling, relaxing of the momentum sum rule, and in the latter case a change in the scale used for the argument of  $\alpha_S$  for high- $x$  evolution. The resulting PDFs are large where it is required for them to compensate for missing higher order corrections, but they are not correspondingly depleted elsewhere. We have compared in detail the different PDF approximations combined with LO MEs to *the truth*, i.e. full NLO, for two processes which probe different types of PDF, ranges of  $x$  and QCD scales. One can conclude that, in general, the results are very positive. The LO\*\* and LO\* PDFs provide the best description compared to *the truth*. In [3] we saw that this was generally true, especially for  $s$ -channel processes, though LO\* gave a slight overestimate for  $t$ -channel processes. We have confirmed that the LO\*\* PDFs give similar results but are in most cases even a little closer to *the truth* than the LO\* PDFs. The improvement compared to the LO or NLO PDFs is particularly the case in terms of the

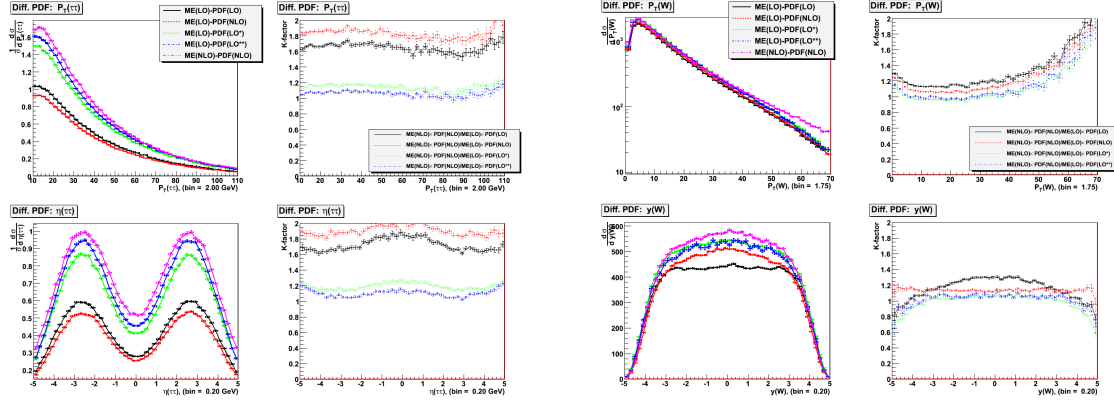


Figure 2: Comparison of Z-boson (left plot) and Higgs (right plot) production. *The truth* and all four approximations are shown.

normalization, but the shape is usually at least as good, and sometimes much better, than when using LO or NLO PDFs. It should be stressed that no modification of the PDFs can hope to reproduce successfully all the features of genuine NLO corrections. In particular we noticed the recurring feature that the high- $p_T$  distributions are underestimated using the LO generators, and this can only be corrected by the inclusion of the emission of a relatively hard additional parton which occurs in the NLO matrix element correction. However, we propose the use of the LO\*, or more correctly, the LO\*\* PDFs if only LO MEs are to be used. Both LO\* and LO\*\* PDFs are now available in the LHAPDF package [13], their names are MRST2007lomod and MRSTMCAL.HGrid respectively.

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